U.S. Department of Energy Distributed Energy and Electric Reliability Program

January 21, 22, and 23, 2003

Ritz – Carlton, Washington D.C.

"How The Future Distribution System Will Change The Nation's Electric Infrastructure"

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Introduction

- Renewables Fall Short
- Will Deregulation Solve the Transmission Capacity Problem ?
- The Greatest Change Will Occur in the Distribution System
- A New Distribution System Will Evolve
- What Will the Future Power Systems Look Like ?

Performance Comparisons

(1) Efficiency and Losses

(2) Investment, Fuel and O&M Costs

(3) Reliability and Power Quality

(4) Emissions

(5) Infrastructure Requirements

(6) Electrical Environmental Effects

(7) Installation Time

(8) Electrical Safety

(9) CCHP Opportunities

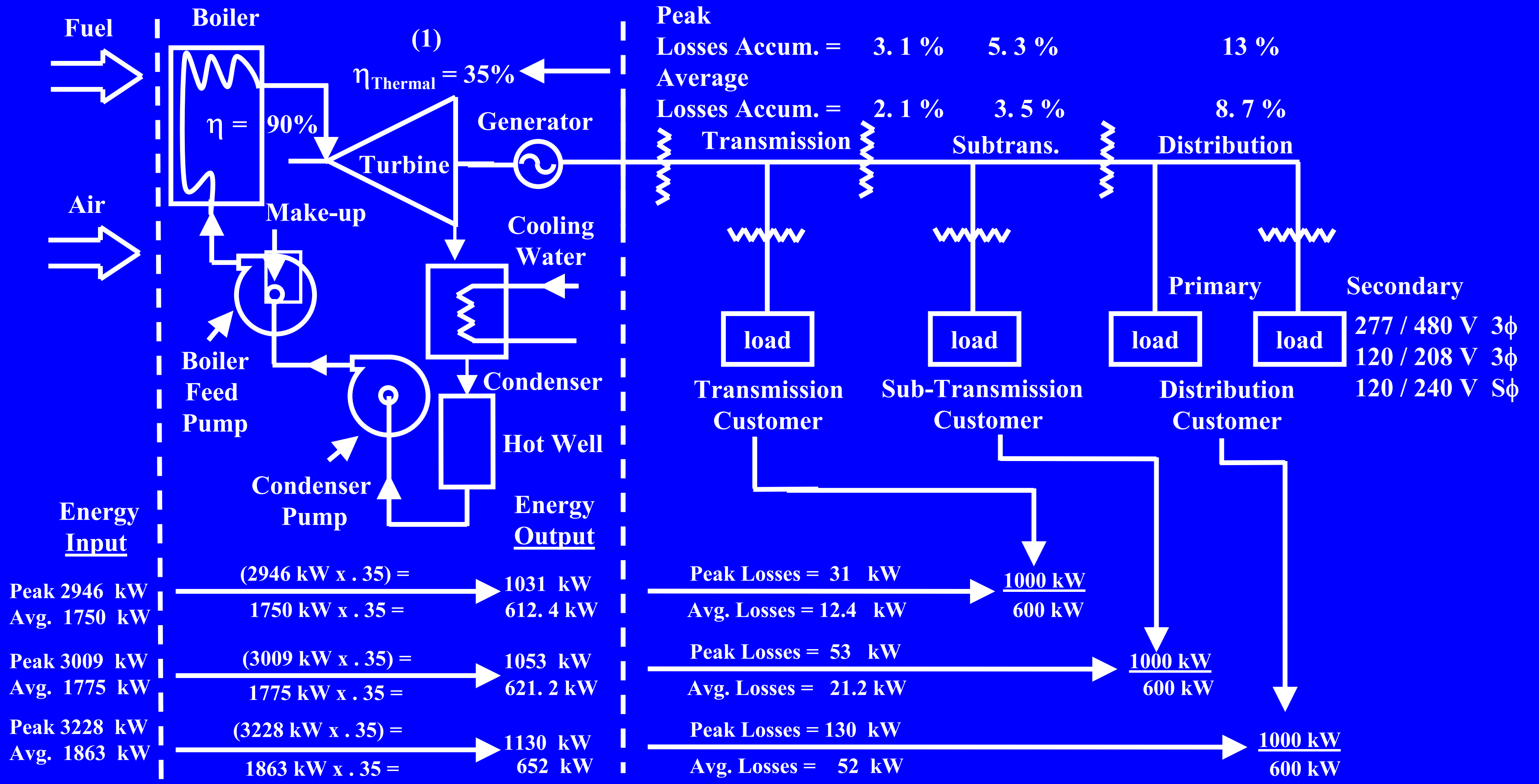
(10) Financial Risk and Security Risk

Two Cases Are Considered

(1) Central Station Generation Coal Fired Steam
Turbine and T&D System

(2) Self Generation Gas Turbine Recuperated Cycle
With & W/O CCHP

Round ① - Efficiency and Losses



	Overall Peak System Efficiency $\eta_{peak\ sys.}$	Overall Average System Efficiency $\eta_{avg.\ sys.}$
Trans.	(1000 kW / 2946 kW) x 100 % = 33.9 %	(600 kW / 1750 kW) x 100 % = 34.3 %
Subtrans.	(1000 kW / 3009 kW) x 100 % = 33.2 %	(600 kW / 1775 kW) x 100 % = 33.8 %
Distribution	(1000 kW / 3228 kW) x 100 % = 30.98 %	(600 kW / 1863 kW) x 100 % = 32.2 %

Figure 1.

Central Station Thermal Power Plant (Coal) and T & D System-Component Efficiencies η, Peak Losses (Capacity), Average Losses (Energy), and Overall System Efficiencies η_{sys}.

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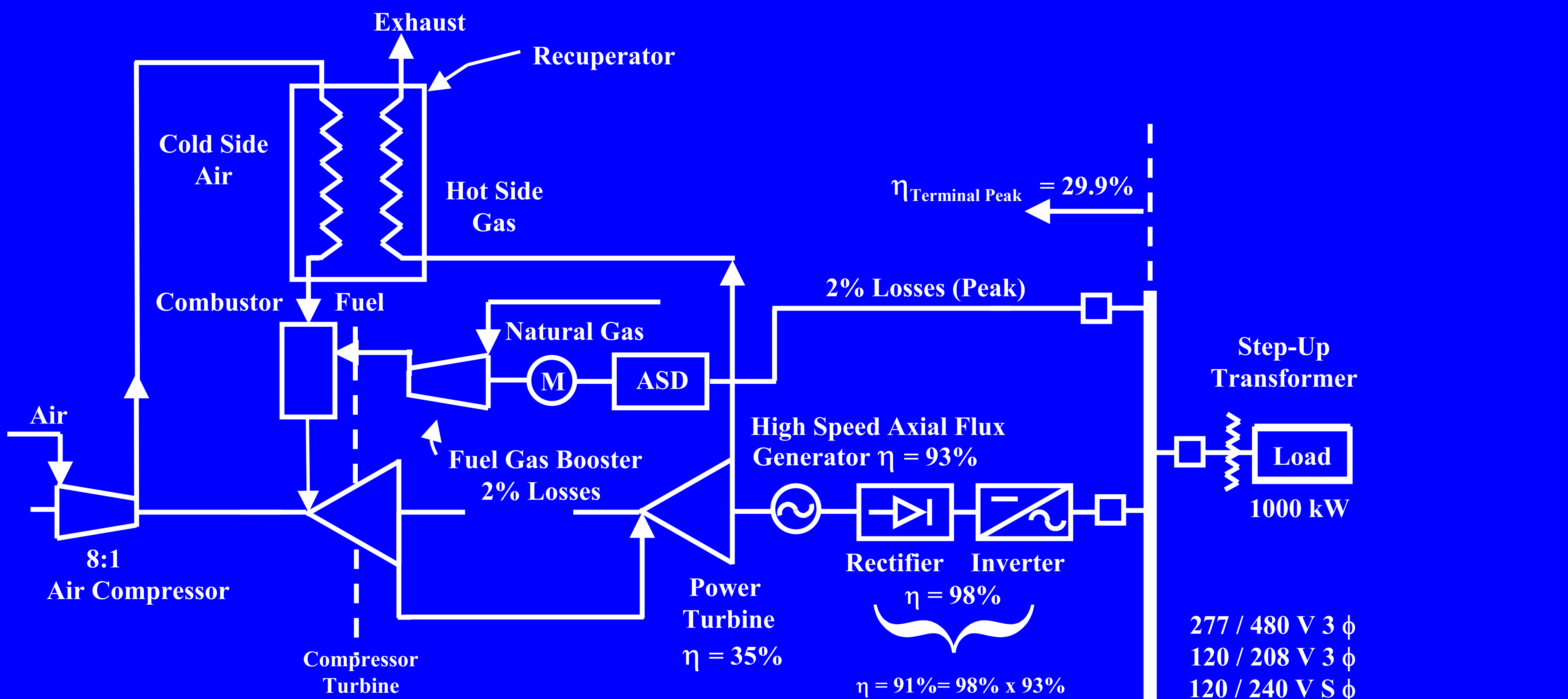

$\eta_{Terminal}$ Peak

η = (.35 x .93 x.98) x 100% = 31.9%

$\eta_{Terminal\ \ Peak}$= 31.9% - 2% Losses = 29.9%

$\eta_{Terminal}$ Average

η = (.331 x .93 x.98) x 100% = 30.17%

$\eta_{Terminal\ \ \ Average}$= 30.17% - 1.8% Losses = 28.37%

Energy Input
Peak 3,402 kW
Average 2,147 kW

3,402 kW x .299 = 1017.2 kW
2,147 kW x .284 = 609.7 kW

Energy Output
1017.2 kW
609.7 kW

Peak Losses = 17.2 kW = 1000kW
Avg. Losses = 9.7 kW = 600 kW

Overall Peak System Efficiency $\eta_{peak\ sys.}$
Distribution (1000 kW / 3402 kW) x 100% = 29.4%

Overall Average System Efficiency $\eta_{avg.\ sys.}$
Distribution (600 kW / 2147 kW) x 100% = 27.9%

Figure 3.

Self Generation Gas Turbine Recuperated Cycle Plant, Component Efficiencies η, Peak Losses (Capacity), Average Losses (Energy) and Overall System Efficiency η_{sys} without CCHP

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Table 1 Round ① - Efficiency and Losses

Central Station Generation Steam Turbine and T&D System (See Figure 4.)

	Generation	Trans.	Subtrans.	Dist.
Overall Peak System Efficiency	35%	33. 9%	33. 2%	30. 98%
Overall Average System Efficiency	35%	34. 3%	33. 8%	32. 2%

Self Generation Gas Turbine Recuperated Cycle w/CCHP and w/o CCHP (See Figure 5.)

	Generation	Trans.	Subtrans.	Dist.
Overall Peak System Efficiency (including fuel gas compressor)				
(W/O CCHP)	29. 9%			29. 4%
(W/ CCHP)	67. 2%			66. 1%
Overall Average System Efficiency (including fuel gas compressor)				
(W/O CCHP)	28. 4%			27. 9%
(W/ CCHP)	63. 6%			62. 6%

Note: Average and peak losses are shown on Figures 4. and 5.

Winner Goes To: Self Generation Gas Turbine Recuperated Cycle w/CCHP

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Cost Comparison

The cost comparison consisted of:

(1) Two 655 MW coal fired plants

(2) 400 kW mini turbines with I / C engines for load following

Central Station Generation:

Actual cost = $1489 / kW or $1500 / kw ⇒ 3.58¢ / kWh

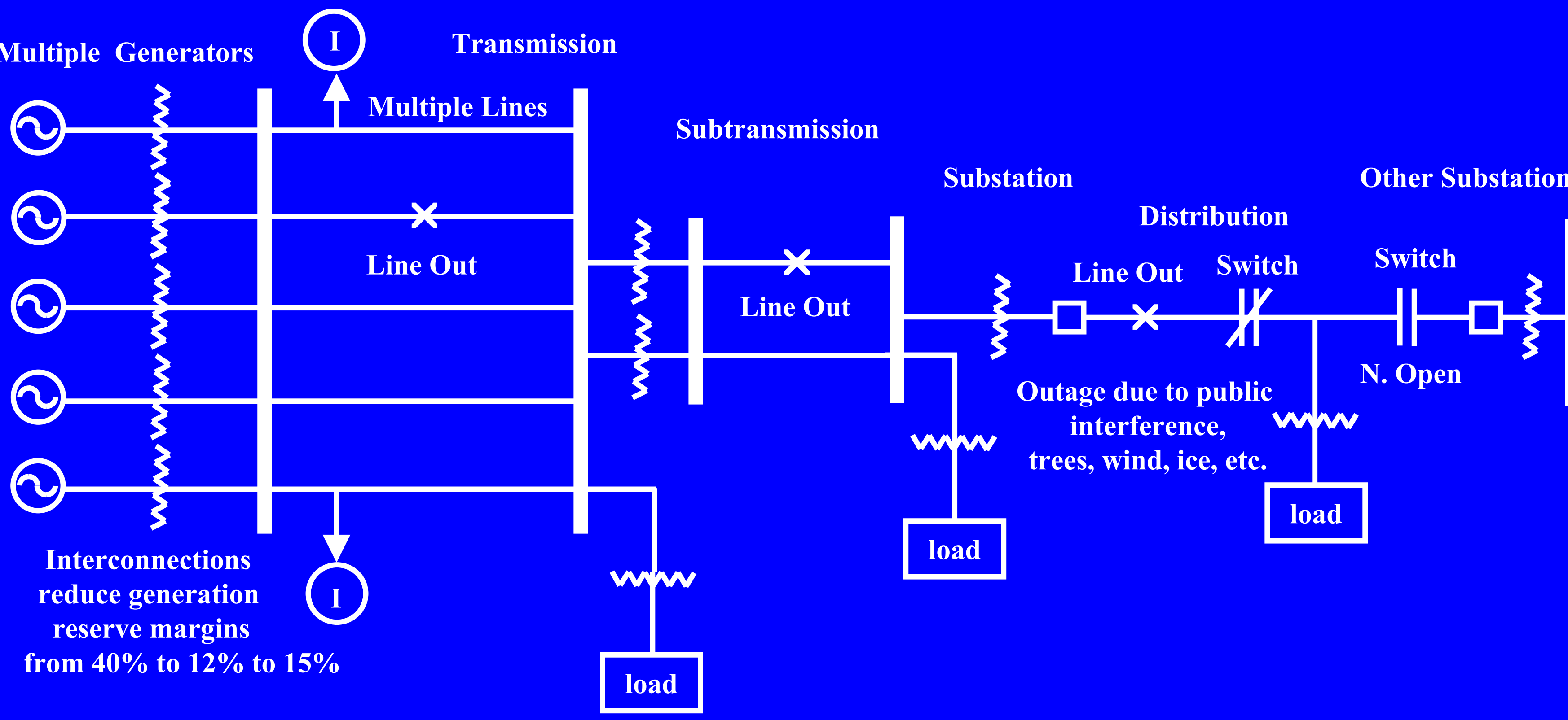
Self Generation:

29.8% reserve margin is higher than central station generation because no interconnections to other utilities

Self Generation	Central Station	Deviations
Investment = 2.60¢	3.58 ¢	27% less
Cost of fuel = 5.4¢ w/o CCHP	1.55 ¢	3.5 x more
Cost of fuel = 2.42¢ w/ CCHP	——	1.6 x more
O & M = 1.00¢	.68¢	
Total = 6.02¢ w/ CCHP	5.81¢	.21¢ more
When Distribution costs T&D are added		
Total = 6.20¢	8.93¢	Self Generation is 30.6% less

Conclusion : Therefore residential and commercial customers have an alternative

Why is the Central Station Generation and T & D Power Delivery System being Challenged?



Transmission

(1) High Reliability - due to multiple lines, multiple generators and multiple interconnections.

(2) Although multiple lines provide improved reliability, the increase in exposure due to the high density of lines and equipment causes many momentary outages and voltage sags.

(3) Also, parallel lines have lower impedance which results in more customers seeing faults on the system.

Distribution

(1) Low Reliability - due to single radial lines

(2) Environmental conditions such as wind, ice trees, etc. cause a few (2-3) sustained outages, and a large number (> 30) of momentary outages.

(3) Distribution automation has reduced the number of sustained outages by providing alternative substation feeds via switches.

Round ③ Reliability - Frequency of Interruption - λ
Where Do Outages Occur ?
λ - Average Data And, Best In Class Utility Data

Transmission	. 015	2. 91%
Subtransmisson	. 10	19. 42%
Primary	. 40	77. 67%
Total	. 515	100. 00%
Subtransmission		
OHL	. 055	55%
UL	. 017	17%
STA	. 028	28%
	. 10	100%
Primary		
OHL	. 35	87. 5%
UL	. 03	7. 5%
STA	. 02	5. 0%
	. 40	100%

Microgrid λ of interruption

$\lambda_{BIC} = 12.5\% \times .40^{(1)} = .050^{(3)}$

$\lambda_{AVG} = 12.5\% \times 1.05^{(2)} = .131^{(3)}$

Note (1): "Best in Class" λ

Note (2): Average λ

Note (3): w / o generation λ's

Round ④ Power Quality

400 kW Gas Turbine Generation: **IEEE 519 :**

Total Harmonic Current Distortion: $THD_I = 5\%$ **$THD_I = 5\%$**

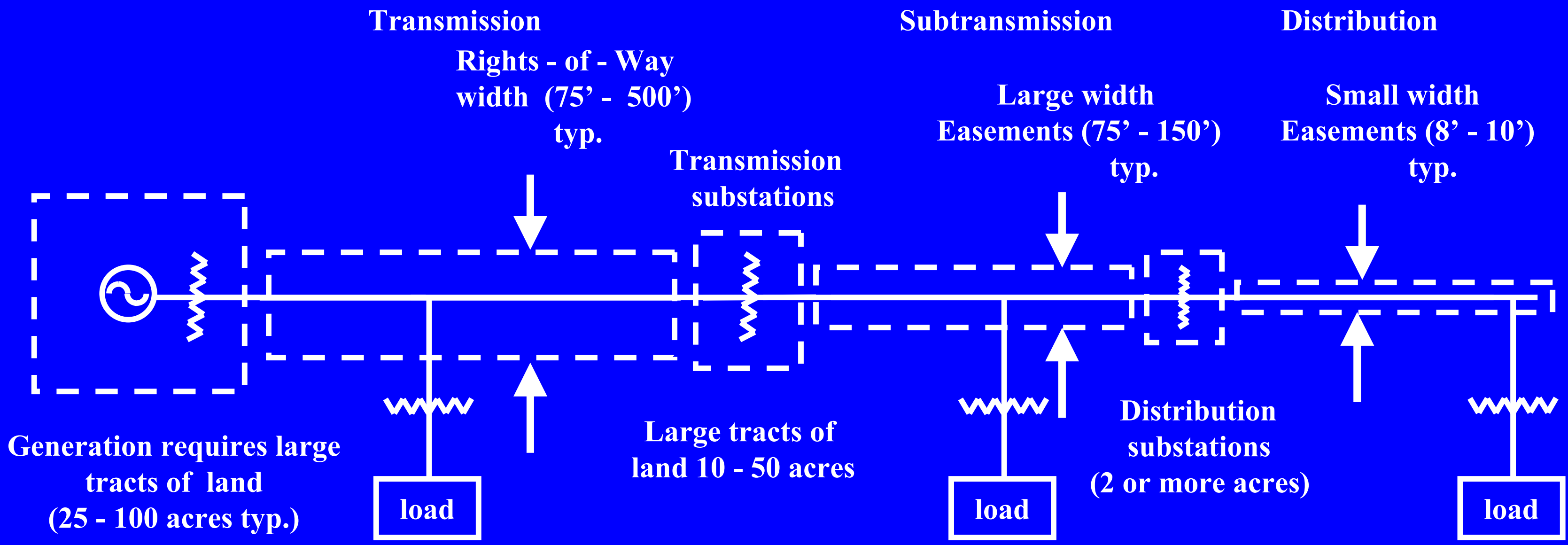
Total Harmonic Voltage Distortion: $THD_V = < 2\%$ **$THD_V = < 3\%$**

Emissions

	Micro & Mini – Turbine			U.S. Coal Generation
		min.		
NO_X	< 10 ppm,	3 - 4 ppm,	.41 lbs / MWh	5.6 lbs / MWh
CO	< 40 ppm,	20 ppm,	1.5 lbs / kWh	1.3 - 2.25 lbs / kWh
SO_2	.01 lbs / MWh			12 lbs / MWh
CO_2	1477 lbs / MWh - 1329 lbs / MWh			2,115 lbs / MWh

Winner Goes To : Self Generation Gas Turbine Recuperated Cycle

Central Station Generation and T & D Power Delivery System Requires Large Physical Space For Infrastructure



(1) Generation and transmission are large users of land - and create visual pollution.
(2) UHV and EHV transmission may have a potential for electric and magnetic biological effects.
(3) Transmission creates corona noise,electric shock, TV interference (TVI), and radio interference (RFI).
(4) Acquiring large parcels of land is very difficult, time consuming, and expensive – legal hassle (11 yrs. to build last transmission line and 91% of all property was previously owned).

(1) Distribution infrastructure is intrusive to residential communities.
(2) To shield substation equipment and reduce noise, walls, trees, and berms are often required around the perimeter of substations.
(3) In densely populated areas, buildings may be required to house facilities.
(4) Tree clearance is a reoccurring expensive maintenance cost and is a controversial procedure for customers to accept.

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Infrastructure

Central Station Generation	Miles	
	Trans.	Dist.
	115 kV & above	
25 - 100 Acres	440,000 total	25,000 each major utility

Electrical Environmental Effects

Transmission

Corona occurs when ⇒ The Electric Field Intensity $\vec{E}$ exceeds the break down strength of air

Corona produces :

(1) Light

(2) Audible noise > 59 dB(A)

(3) Radio Interference RI

(4) Television Interference TVI

(5) Conductor vibration

(6) Ozone

(7) Dissipated energy

Electric Fields ⟶ 2 to 5 kV / m

Magnetic Fields ⟶ .1 to .5 gauss

Installation Time

Central Station & Transmission	Distribution	Self Generation
7- 10 yrs.	6 mon. to 2 yrs.	$\leq$ 6 mon.

Electrical Safety

Distribution

- All Overhead
- Ungrounded Delta
- High Impedance
  Faults on Y grounded distribution

Self Generation

- All Underground
- Y grounded distribution

Financial Risk & Security Risk

Less Financial Risk With DR

DR

- Small unit sizes to match incremental load increases
- Short lead times based on 6 month load forecasts

Central Station and T&D

- Huge financial investments required for Central Station and Transmission & Distribution
- Long lead times based on 10 year load forecasts can be very uncertain

Less Security Risk With DR

Central Station

Small number of large MW sizes

Self Generation

Large number of small kW sizes

Performance Comparison Round Number's		Winner: Central Station, & T&D	Winner: Self Generation
(1) Efficiency & Losses	w/o CCHP	✓	
	w/ CCHP		✓
(2) Investment, Fuel and O & M Costs	w/o CCHP	✓	
	w/CCHP		✓
(3) Reliability & Power Quality			✓
(4) Emissions			✓
(5) Infrastructure Requirements			✓
(6) Electrical Environmental Effects			✓
(7) Installation Time			✓
(8) Electrical Safety	Primary	✓	✓
	Secondary		✓

	Winner	
Performance Comparison Round Number's	Central Station, & T&D	Self Generation
(9) Combined Cooling, Heating, & Power Opportunities		✓
(10) Financial Risk & Security Risk		✓
Final Winner is Self Generation With CCHP		

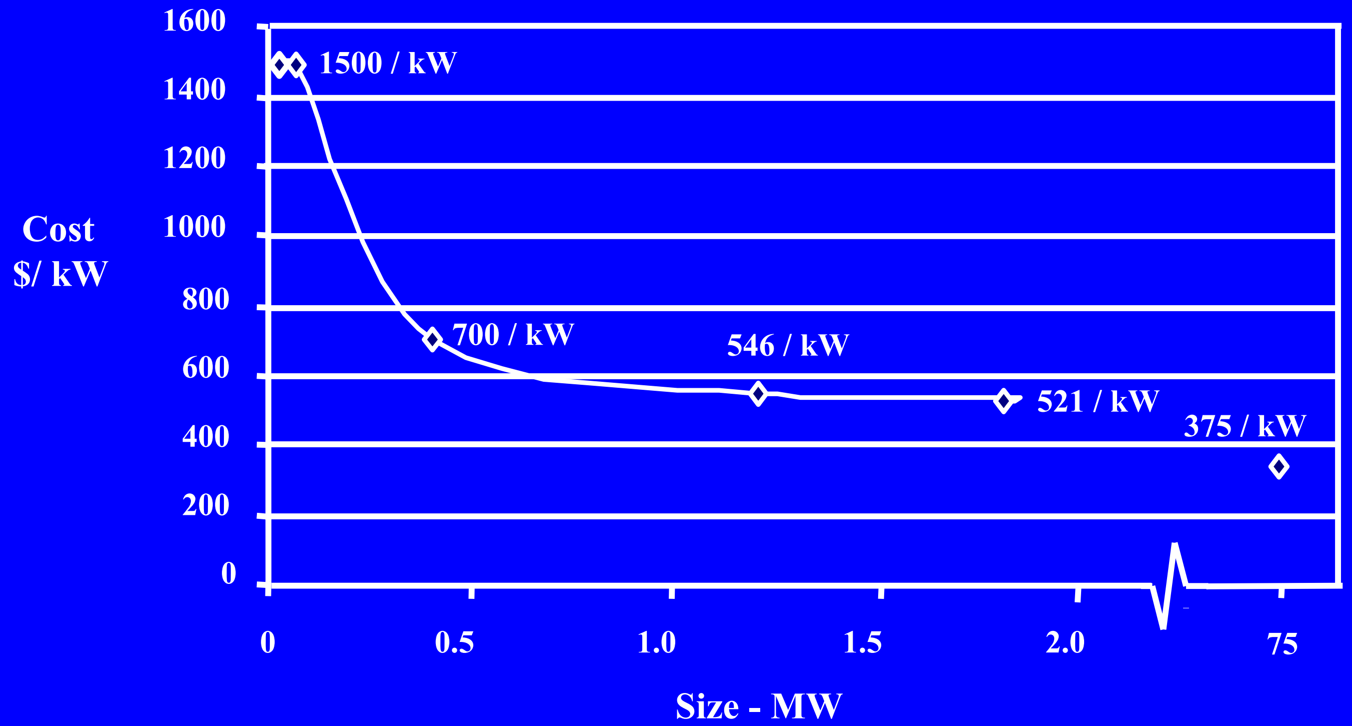


Figure 2. The Economy of Scale of Gas Turbine Generators Indicates The Ideal Size Ranges From 250-500 kW for Microgrid Applications

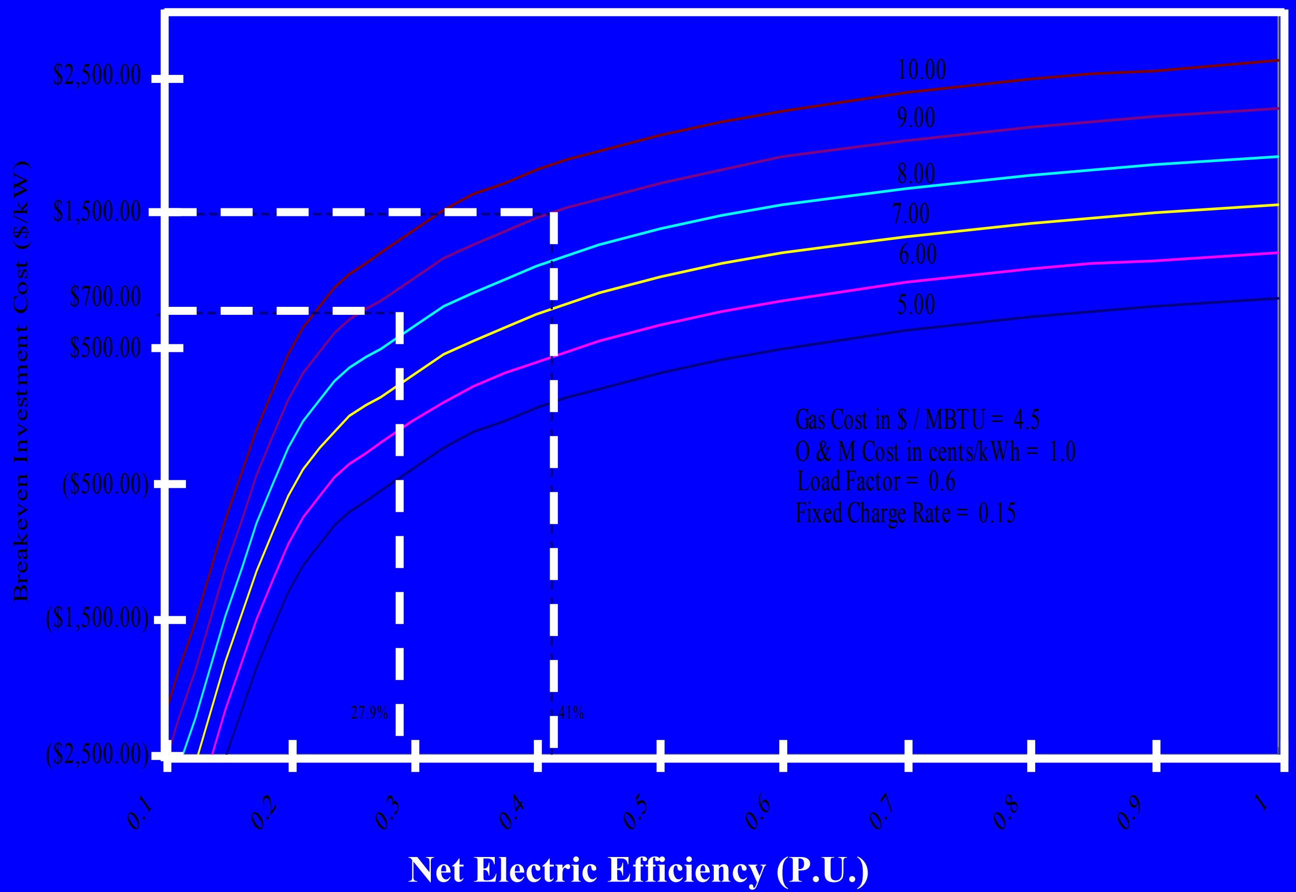


Figure 3. Dollar / kW of Investment vs. Net Electric Efficiency to Break Even With Grid Energy Cost

Why A System Of Generating Units Serving Aggregated Loads ?

	(N = 1)		(N = 24)
1. Lower diversified demands	17.80 kVA	→	5.13 kVA

2. Lower generation capability

3. Load profile is more stable

4. Reduced Load Following requirements

5. Higher efficiency

6. Lower reserve margins

7. Higher reliability : 95 % - 98 % availability results in 438 → 175 hrs of outage vs. 99.99 % → 53 minutes of outage

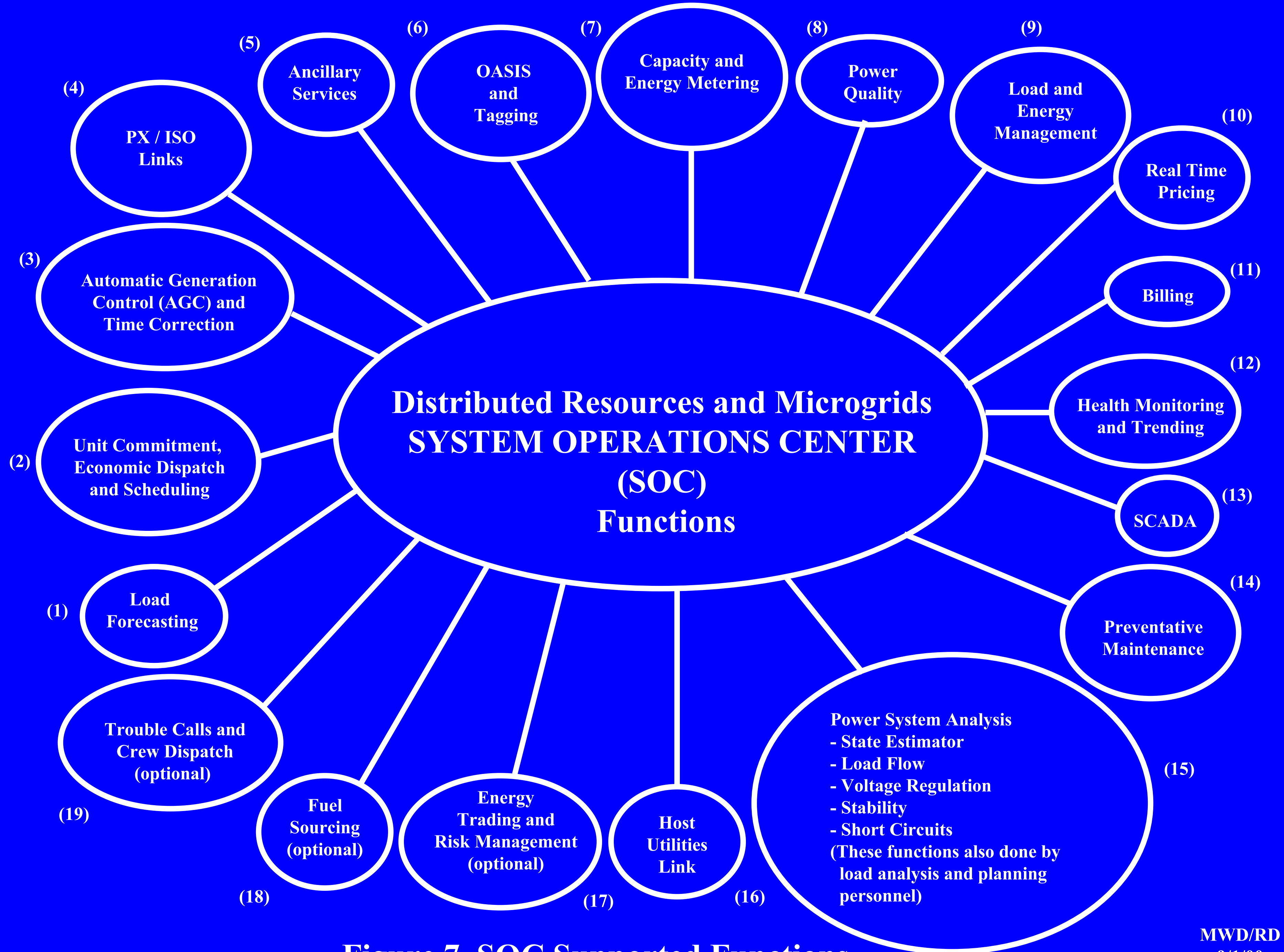


Figure 7. SOC Supported Functions

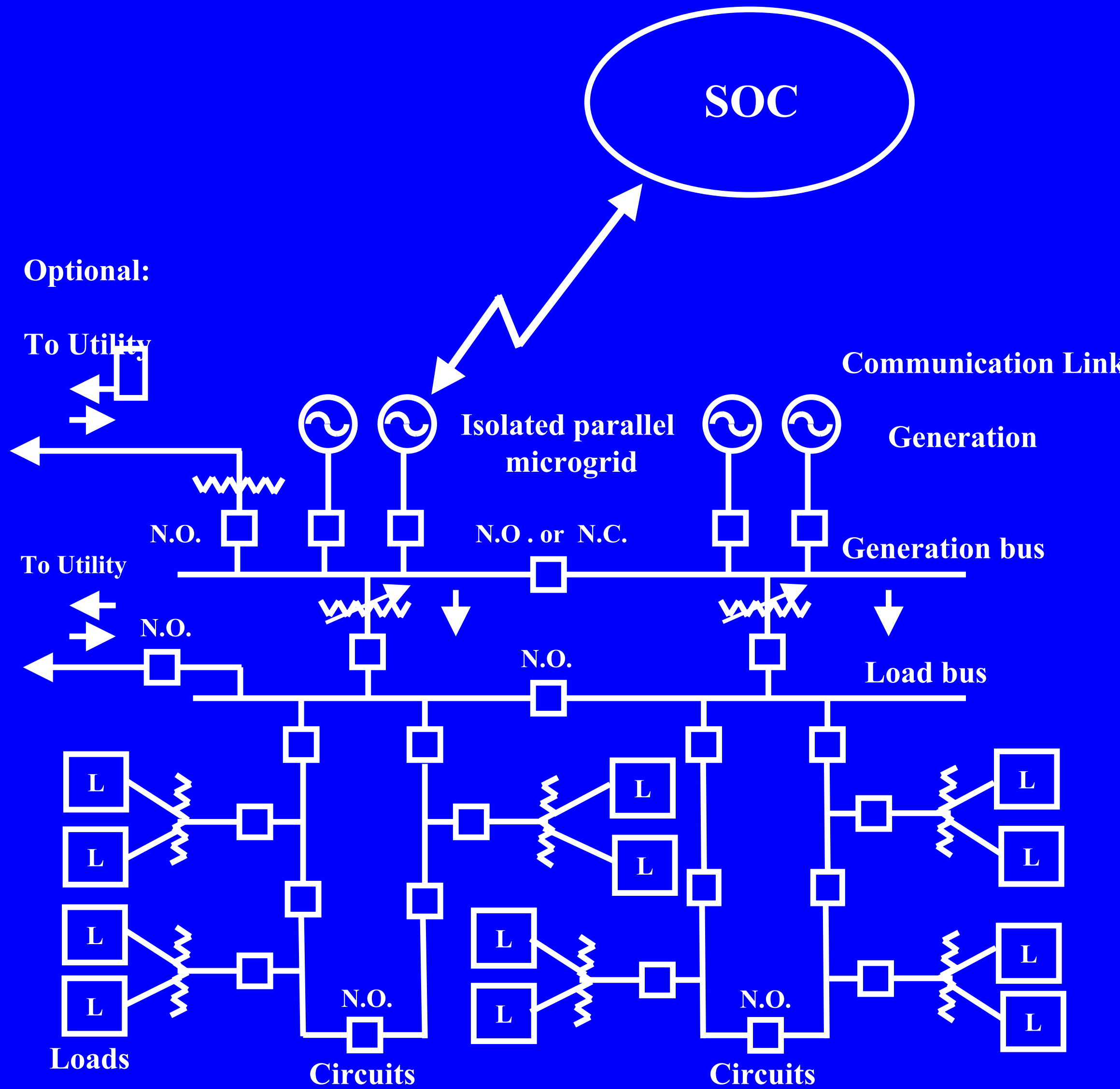


Figure 8. Microgrid Configuration

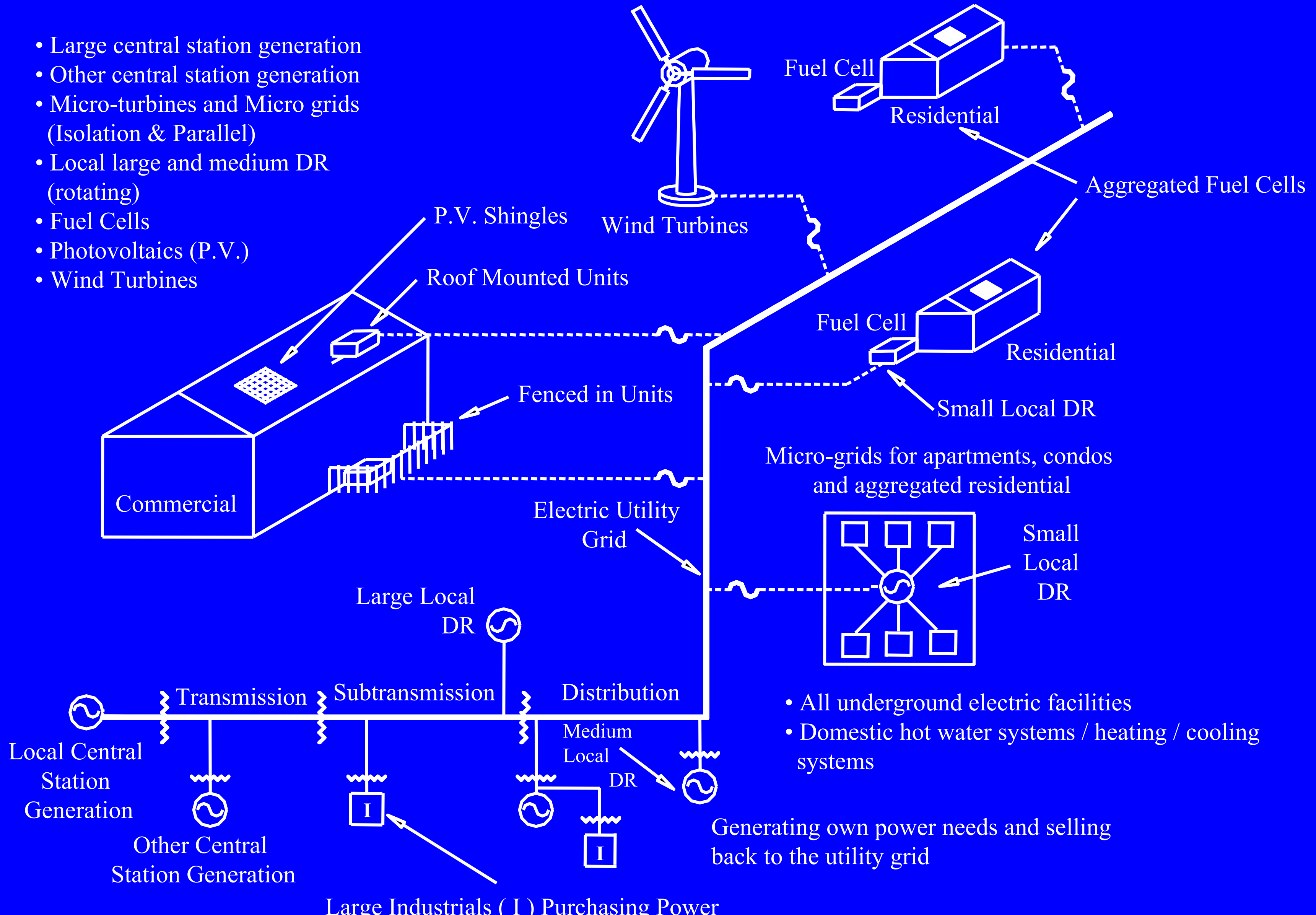


Figure 3. "What will the Future Power System look like?"

MWD/JCP
12/07/2000

The New Electric Power Infrastructure Requires:

1. A Portfolio Of Products To Be A Player In The New Electric Energy Business:
   (a) Photovoltaics
   (b) Wind
   (c) Fuel Cells
   (d) External Heat Engines
   (e) Gas Turbines
   (f) I/C Engines
   (g) Storage/Flywheels

2. Sizes Ranging From
   25 kW $\longrightarrow$ 2 MW's
   To Serve All Loads

3. Microgrids And Modular Generation Components w/ and w/o CCHP Components

4. Low Cost, High Efficiency, High Availability
   (\$500) (40%) (98%)
   Low Emissions Generation.
   (< 7 ppm NO_X)
   (< 10 ppm CO)

5. SOC To Monitor/Control Generation Throughout The World via Internet.

6. Telecom Integrated With Power Systems.

7. Availability Of Natural Gas For Most Markets

FC Series – Fuel Cells

plug power

75 kW

IC Series –
Internal Combustion Engines

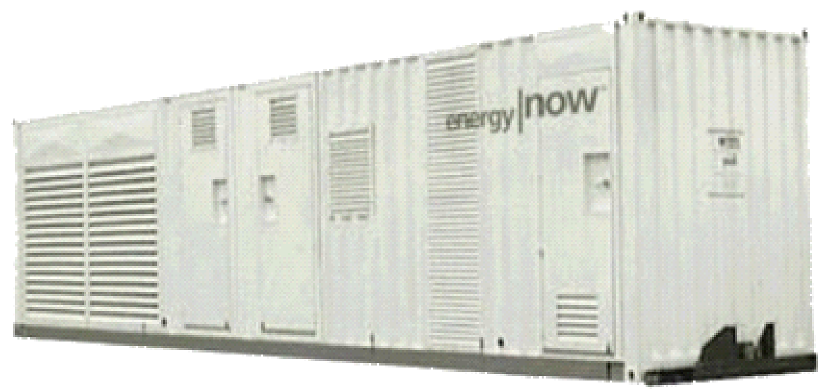
75 and 150 kW

T Series – Mini Gas Turbines

TURBO GENSET

375 to 700 kW

IC Series – Mid-Range



DRESSER
Waukesha

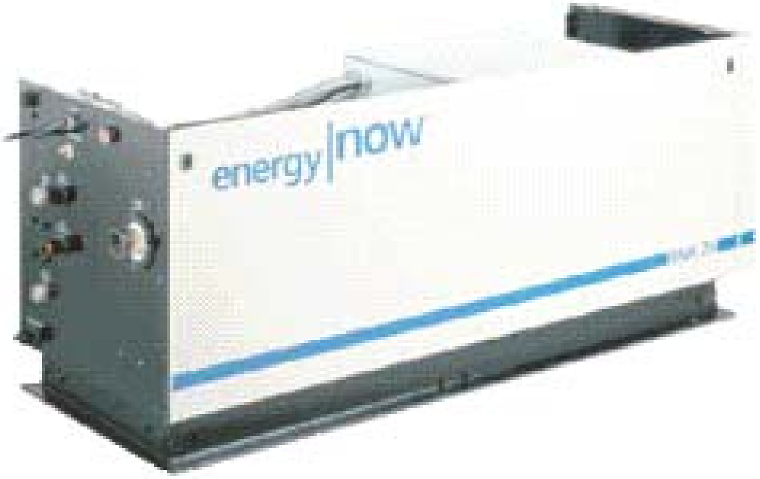
280 to 830 kW

IC Series – ENI 1000

DEUTZ

1 MW

XC Series –
External Combustion Engines



STM POWER

25 kW

Integrating DR's Into Existing Electric Distribution System Will:

(1) Improve Reliability And Power Quality

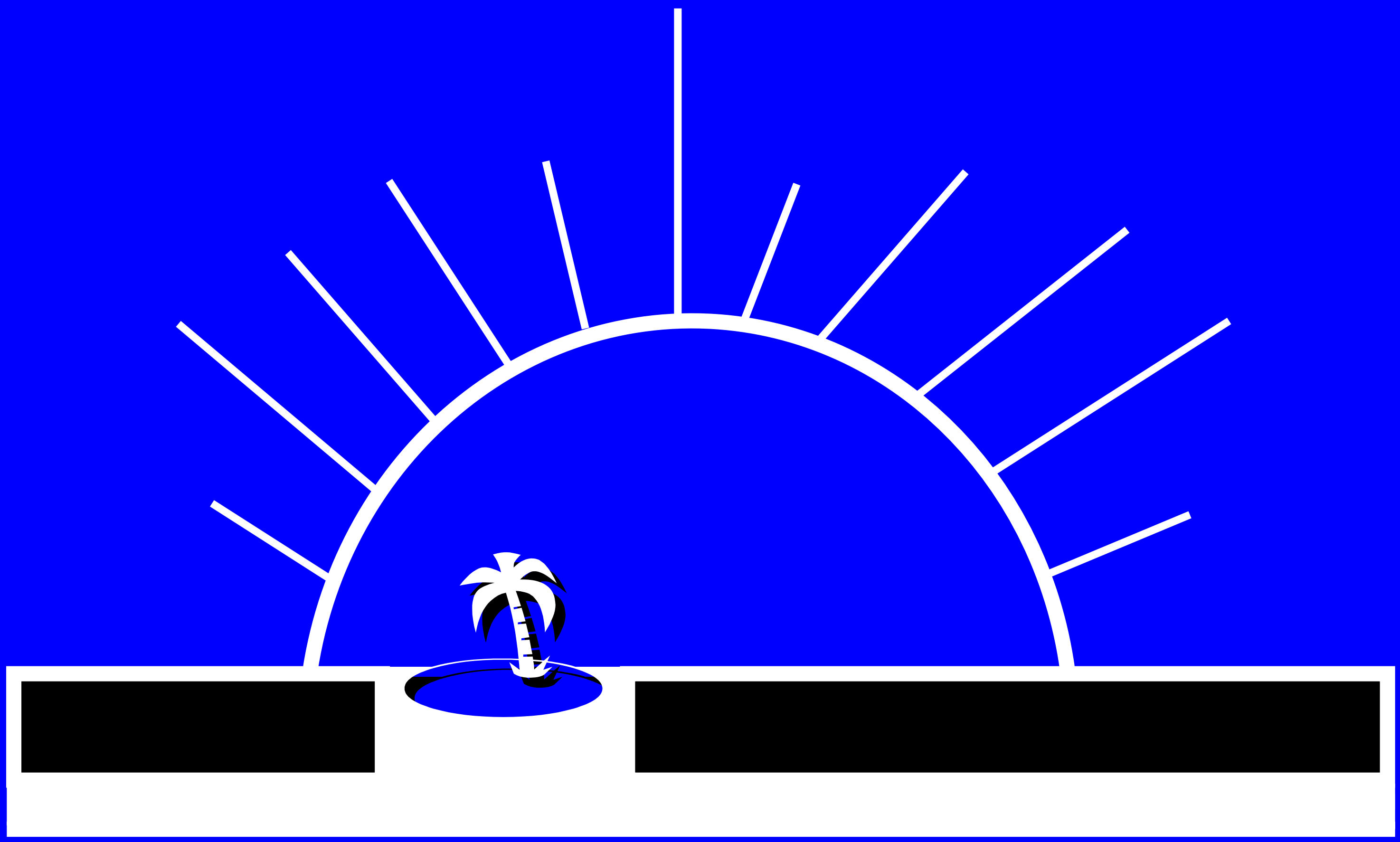
(2) Reduce Thermal Overloads

(3) Improve Voltage Regulation

(4) Reduce Cost

(5) Improve Efficiency And Reduce Losses

(6) Reduce Emissions



The Dawn Of A New Horizon

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1/7/03